Use of Recycled ASR PCC Materials in HMA Airfield Pavement

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Acknowledgement

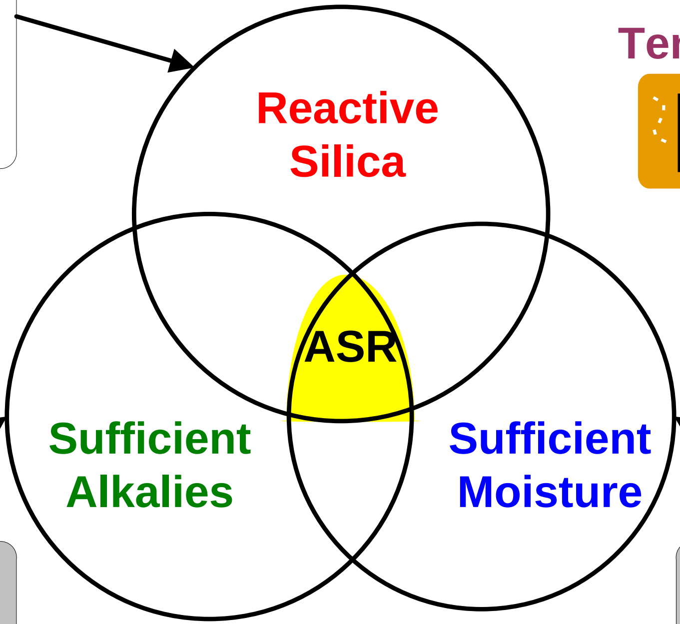
Airfield Asphalt Pavement Technology program (AAPTP)

Project (06-2) Title: Use of Recycled ASR PCC Materials in HMA Airfield Pavement

What is ASR?

Reactive Minerals

- Amorphous silica
- Cryptocrystalline quartz
- Strained quartz
- Tridymite
- Crisobalite
- Opal
- Volcanic glass



Temperature

Sufficient Alkalies

- Portland cement
- SCMs
- Aggregate
- Chemical admixtures
- External sources (seawater & de-icing salt)

Sufficient Moisture

- RH not < 85%
- External sources

Introduction

- **If the damage caused by ASR is significant, removal of portland cement concrete is needed**
- **Making recycled concrete aggregate (ASR-RCA) and find suitable applications for re-use is the best way to avoid disposal issues and promote sustainability**

Type of Applications	Advantages / Issues
Making base materials	**Exposure to moisture would be undesirable**
Making new Portland cement concrete	**May create favorable situation for new ASR as optimum requirements for all the three criteria can be satisfied** *(Gottfredsen and Thogersen, 1994; Xinghe and Gress, 2006)*
Making Hot Mix Asphalt (HMA) concrete	• **Common Issues as in conventional RCA** • **Occurrence of new ASR** • **Role of pre-existing microcracks and gel (?)**

Common Issues of Using RCA in HMA

- **Mortar portions adhered to aggregate makes RCA porous and absorptive**
  - **Higher binder and air void contents**
- **RCA has greater potential to break down**
- **Inconclusive stripping results in HMA**
- **Reduction in bond strength and abrasion resistance**

<u>References:</u> Anon, 1984; Heins, 1986; Paranavithana and Mohajerani, 2006; Wong et al., 2007; Cross et al. 1996; Ryerson University in collaboration with the Ministry of Transportation of Ontario, Canada

Possibility of Occurrence of New ASR in HMA Made using ASR-RCA

A. Reactive silica

- **Generation of fresh reactive surfaces during crushing**

B. Source of high pH and alkalis

- **The mortar portions of the RCA can create high pH situation if sufficient moisture is available in HMA**
  - **Moisture – (i) Infiltration, diffusion, capillary rise, (ii) Moisture damage**
  - ***pH of RCA-water mixtures often exceeds 11.0*)**
- **Additional alkalis from de-icing chemicals and other sources (infiltration / diffusion)**

D. Nature of reaction

- **Isolated – not an issue**
- **Global – could be an issue**

Objectives

Provide guidance on the use of ASR-RCA in HMA airfield pavements through

- **Identifying the possible mechanisms that may create new ASR within HMA**

- **Assessing the effects of pre-existing reaction products (e.g., ASR gel) and micro-cracks in RCA on HMA performance and moisture susceptibility**

- **Identifying potential remedial measures to prevent any new ASR as well as avoid the negative effects of existing ASR.**

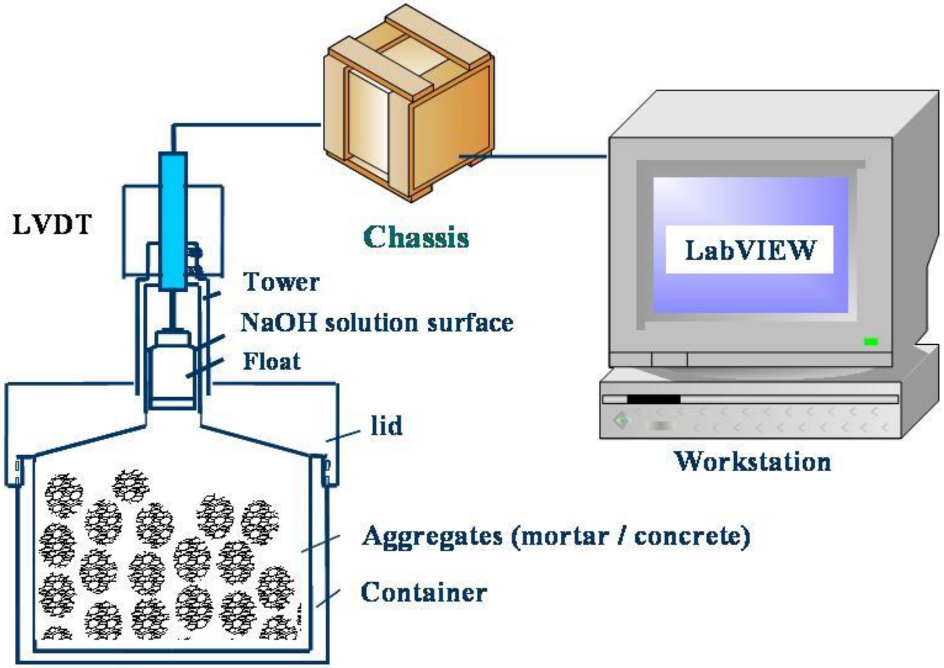
Materials

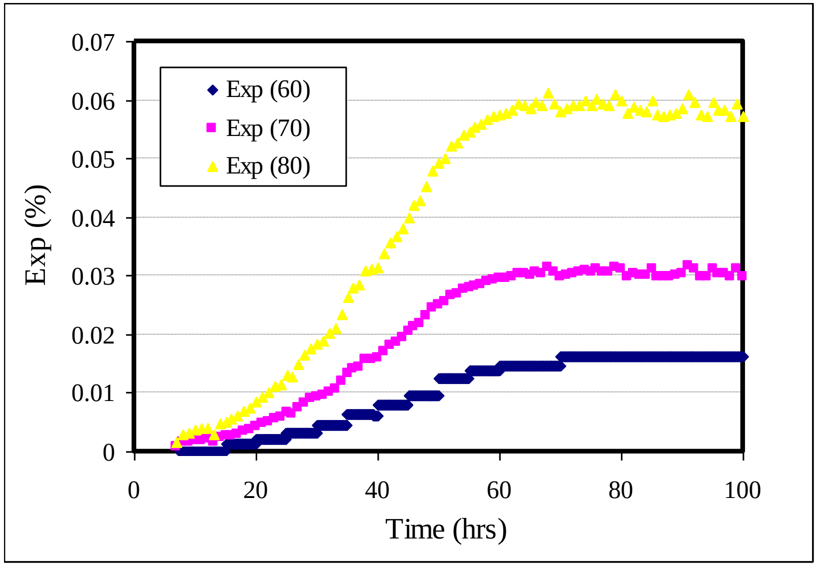
- Two ASR-RCAs (ASR-RCA-1 and 2) and a reactive virgin chert aggregate
- A PG 76-22 asphalt binder
- NaOH solution (0.5N and 1N) saturated with $Ca(OH)_2$
- Additional testing with a deicing chemical (i.e., potassium acetate).

Laboratory Testing Approach

Test Methods	Materials / Specimen Type	Purpose
Petrography (ASTM C 856)	ASR-RCAs	Identification of ASR features
Dilatometer, soak solution chemistry, microstructures	ASR-RCAs, Compacted cylindrical HMA (FAA P401) specimens	ASR potential, other chemical interactions
Beam Test (similar to ASTM C 1293)	Compacted HMA beam (SMA 32.13.17)	ASR potential
Lottman test (ASTM D 4867), cylinder, 60 C/24hr.)	Compacted HMA (P401)	Moisture damage
Microcalorimeter	ASR-RCAs (150-75µm)	Determination of adhesive bond between aggr. and binder
Freezing and Thawing (AASHTO T 103), Micro-Deval (ASTM D 6928)	ASR-RCAs	Effect of presence of microcracks and gel
DSC-TGA	Artificial gel	Effect of heating on ASR gel

Dilatometer: Measures Free volume Expansion% due to ASR





- •Sample of any dimensions
- •No aggregate crushing (testing as-received aggregate)
- •Short testing period – 5 days
- •Fixed aggr / solution ratio
- •Fixed gradation
- •Based on the direct measurement of expansion of ASR gel produced

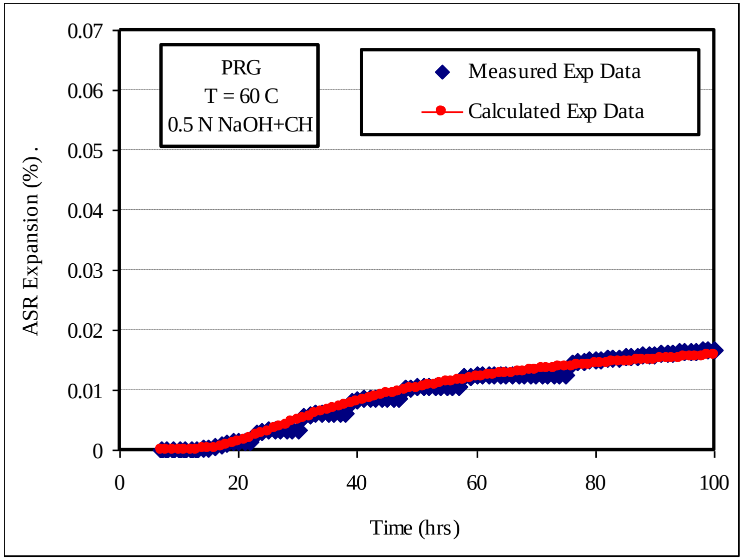
Equipment and procedure

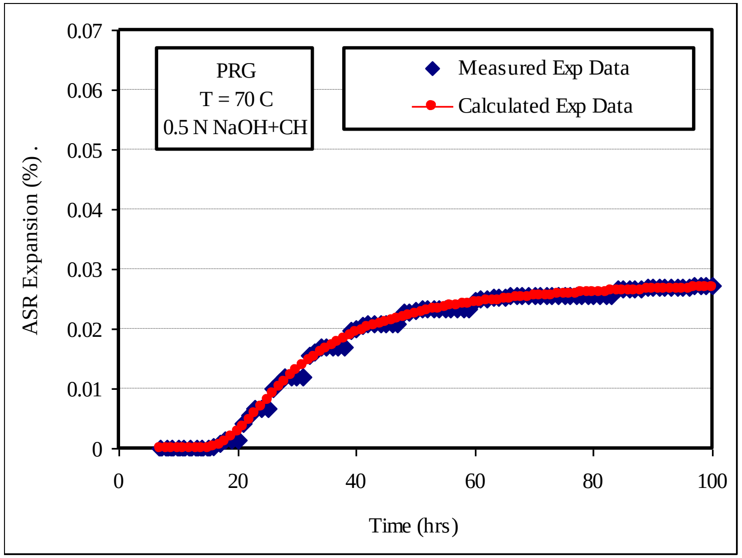
- Better design
- Steel float
- 2 stages vacuuming
- Oven
- Calibration

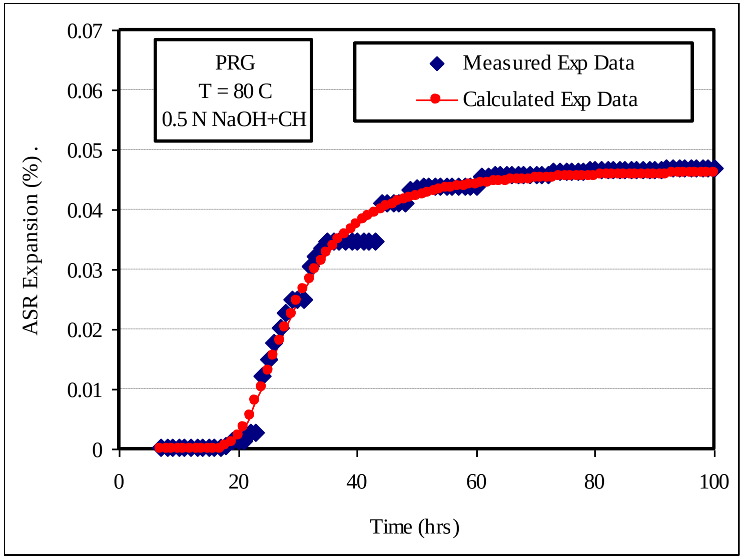
No. of Aggr.	Alkalinity	T
1	3	3
2 replicas, 24 test runs, 15 days period 8 dilatometers run simultaneously at one T		

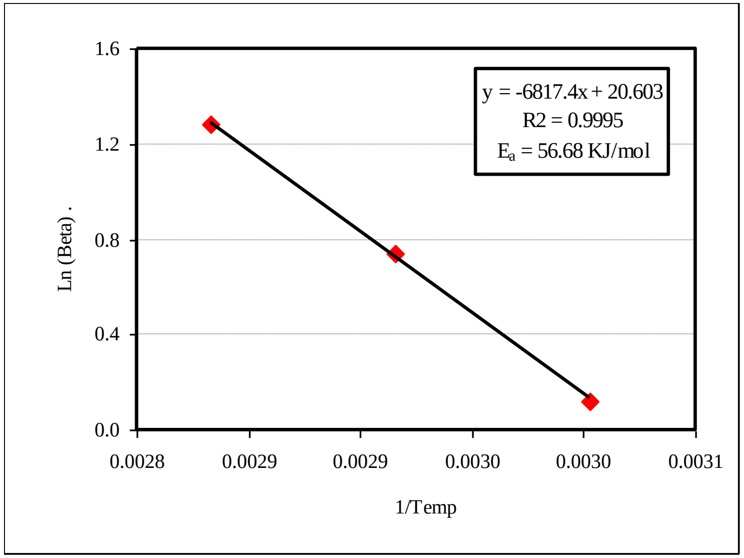
Data Acquisition System

Typical Expansion Results in Dilatometer, Aggr-Solution Reaction









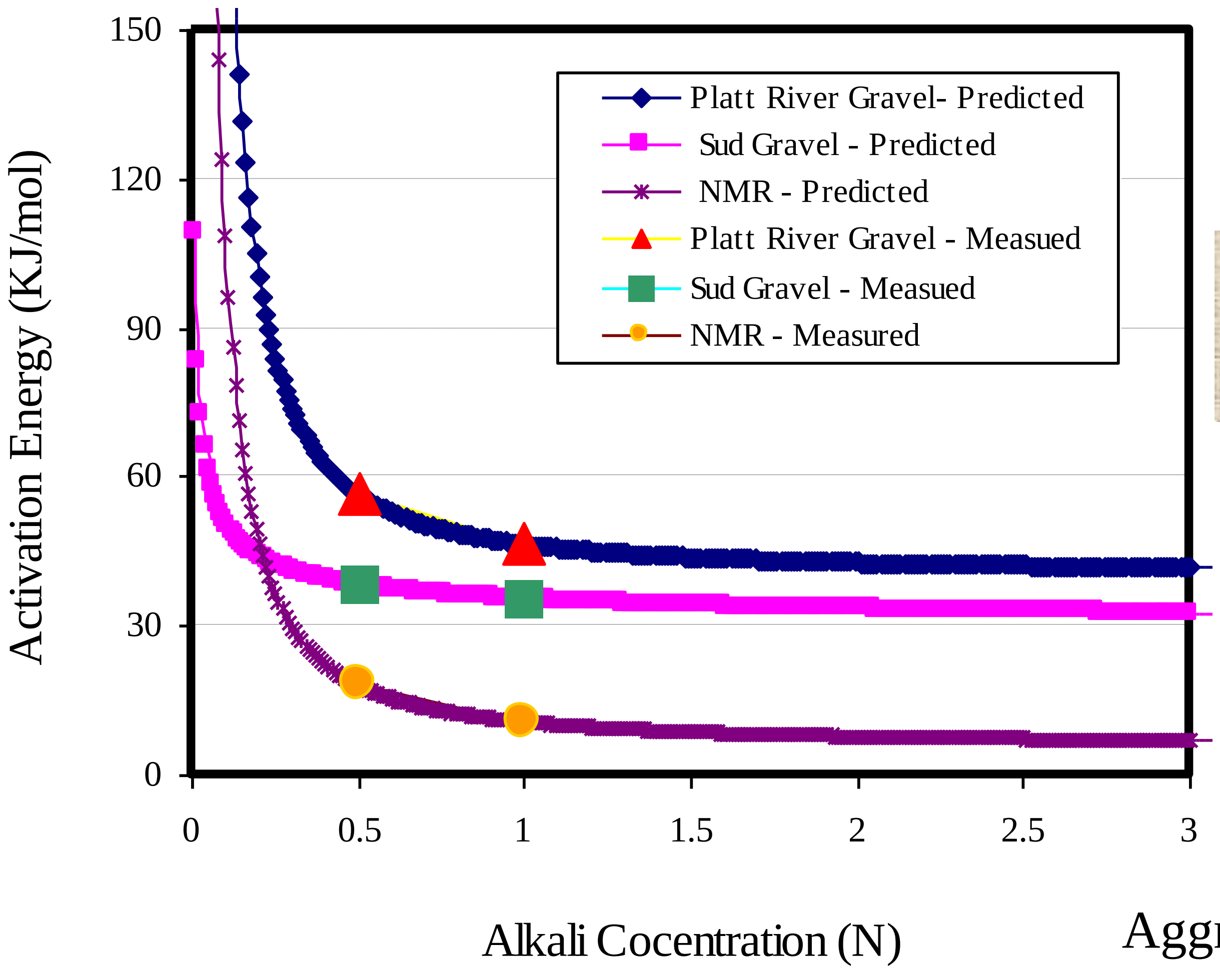
0.5N NaOH + CH

A Combined Approach of Monitoring Test Solution Chemistry and Expansion

Test Solution Alkalinity	Temp (°C)	% Reduction of Na^+	% Reduction of $(OH)^-$	Ult. Exp. (%)	E_a (KJ / mol)
1N NH + CH	60	32	86.16	0.1030	10.72
	70	39	86.35	0.1134	
	80	43	87.78	0.1190	
0.5N NH + CH	60	24	58.22	0.0695	18.09
	70	33	62.59	0.1023	
	80	37	68.16	0.1070	
0.25N NH + CH	60	13	21.66	0.0418	34.28
	70	15	24.14	0.0537	
	80	20	38.06	0.0625	

NMR

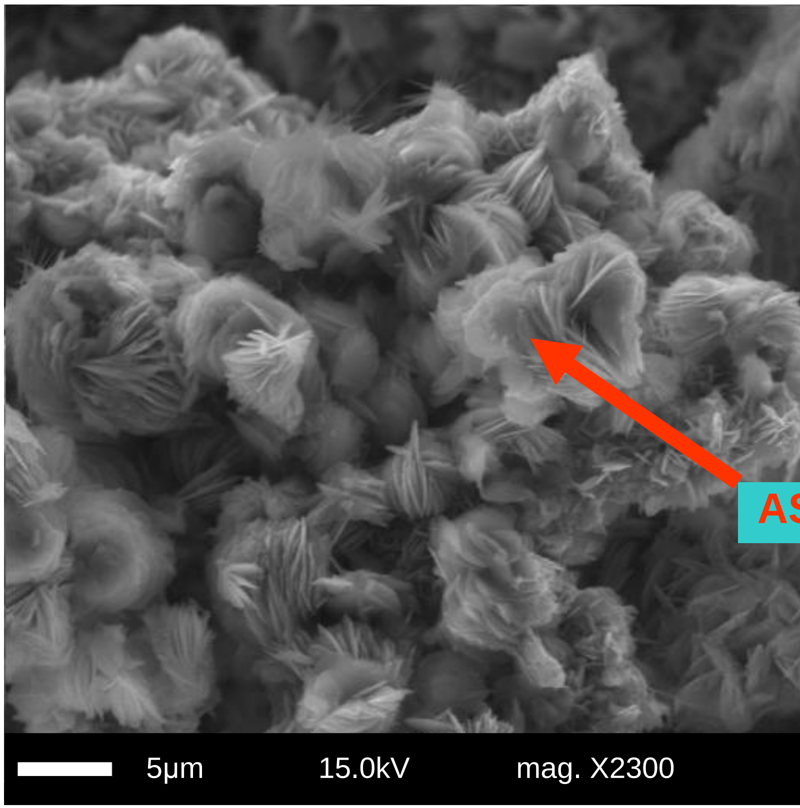
Aggregate Reactivity: Activation Energy vs. Alkalinity



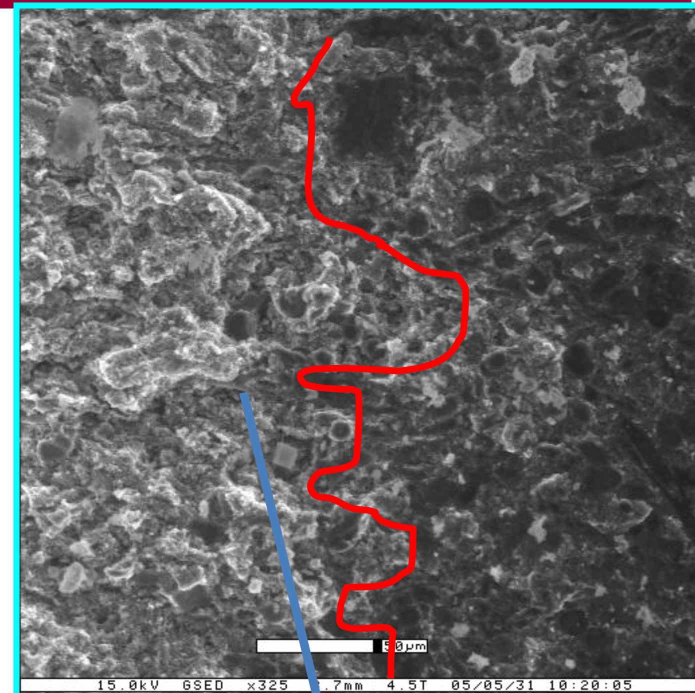
$$E_a = E_{a_0} + \frac{C_1}{C^n}$$

Aggr-solution tests

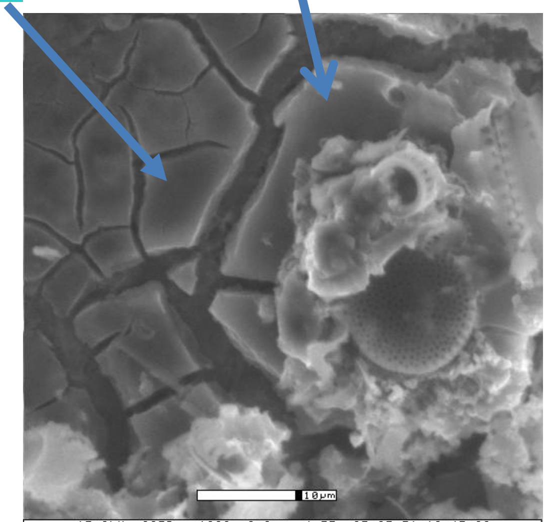
Reaction Products on Aggregate Surface



New Mexico Rhyolite (1N @80ºC), 72 hours



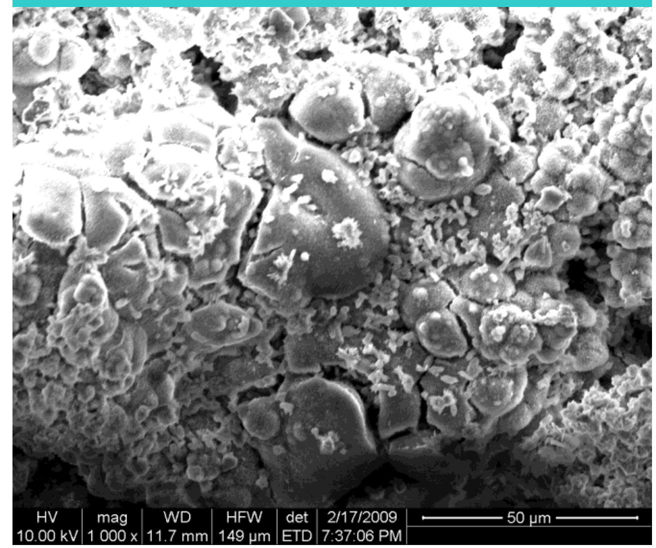
ASR products

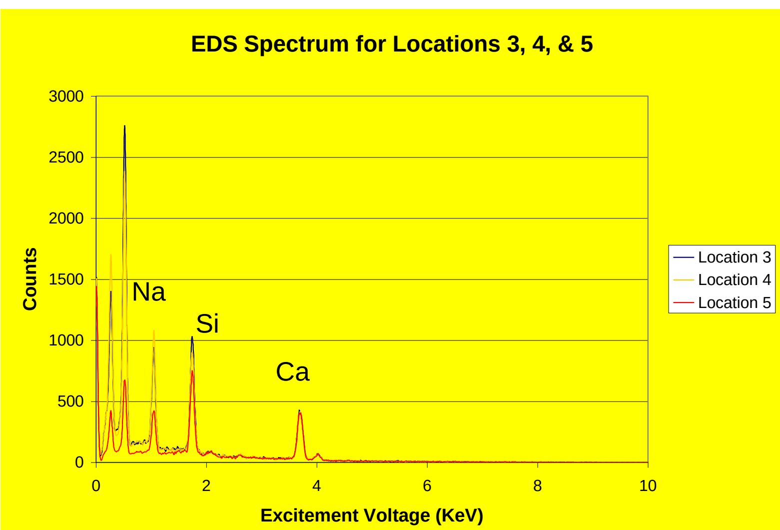


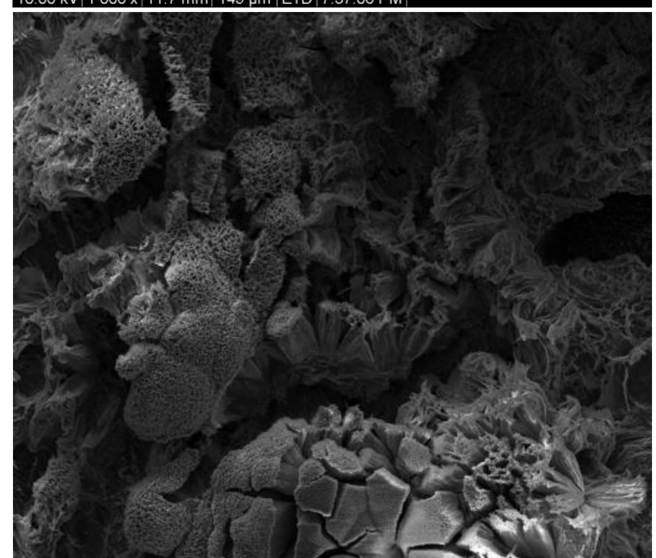
Reacted Opal Particles

Reaction Products on Polished Chert Specimens

0.5N NH + CH, 60ºC, 7 days







0.5N NH + CH, 60ºC, 28 days

RESULTS AND DISCUSSION

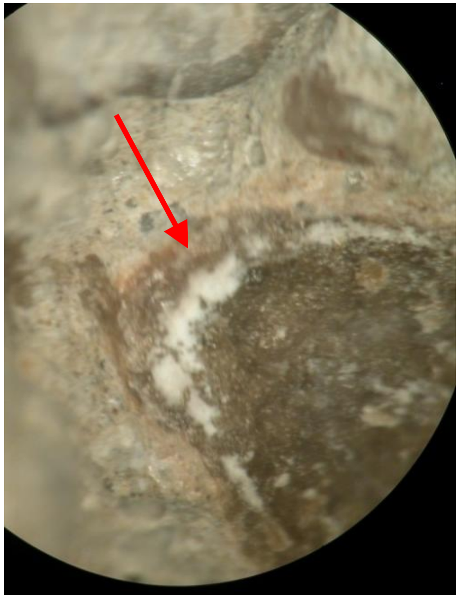
ASR-RCA-1

- Fine aggregate is reactive
- Top 2-3 inches are affected
- No de-icer
- Mild climate

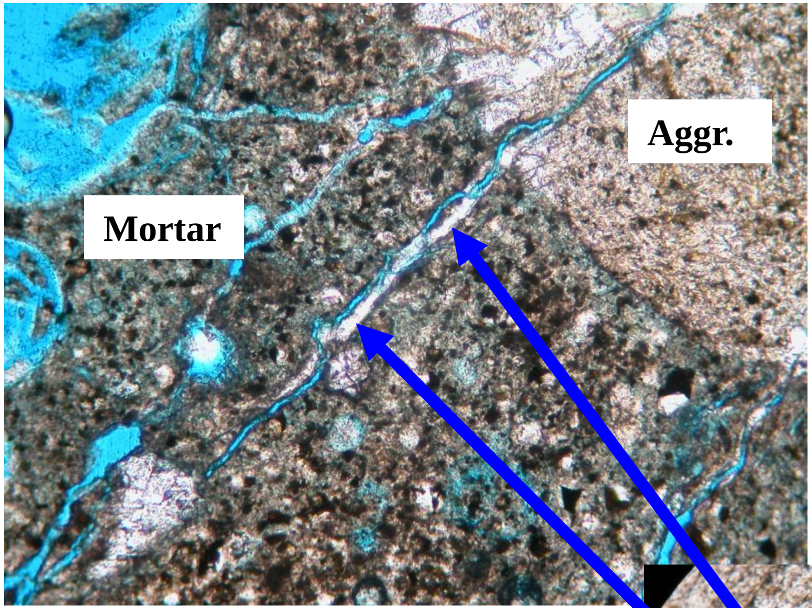
Taxiway

Petrographic Observations: ASR-RCA-1

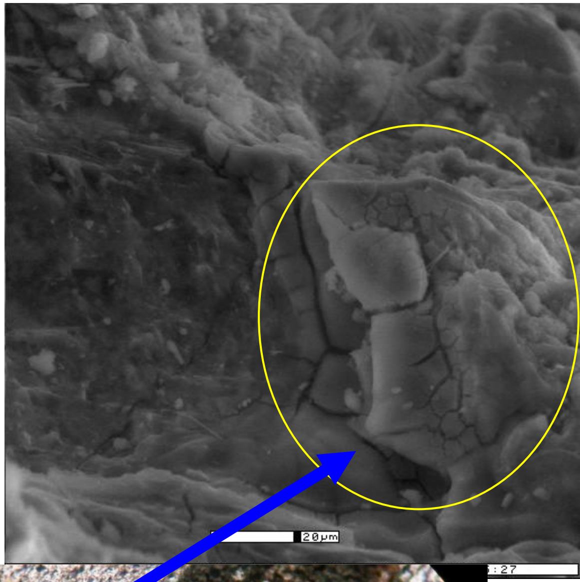
Stereomicroscope



Thin section / OM



ESEM



ASR-RCA-2

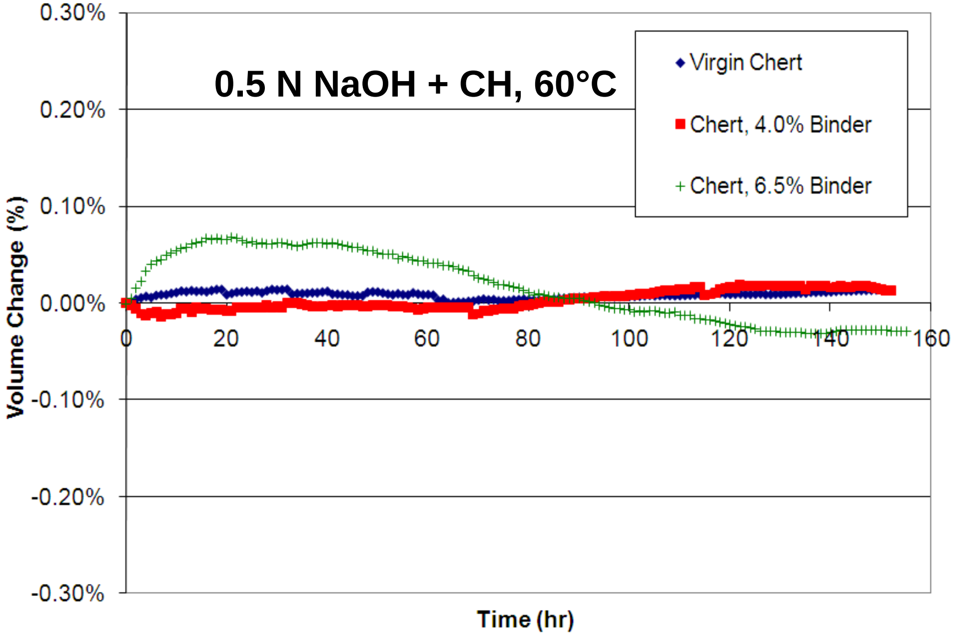
ASR gel on the surface of an RCA particles

Crushing of PCC Chunks

Sieving, accumulation of different size fractions, and mixing with pre-determined proportions to generate materials with fixed gradation

TTI, TAMU

Dilatometer ASR Testing for HMA made Using Virgin Chert Aggregate

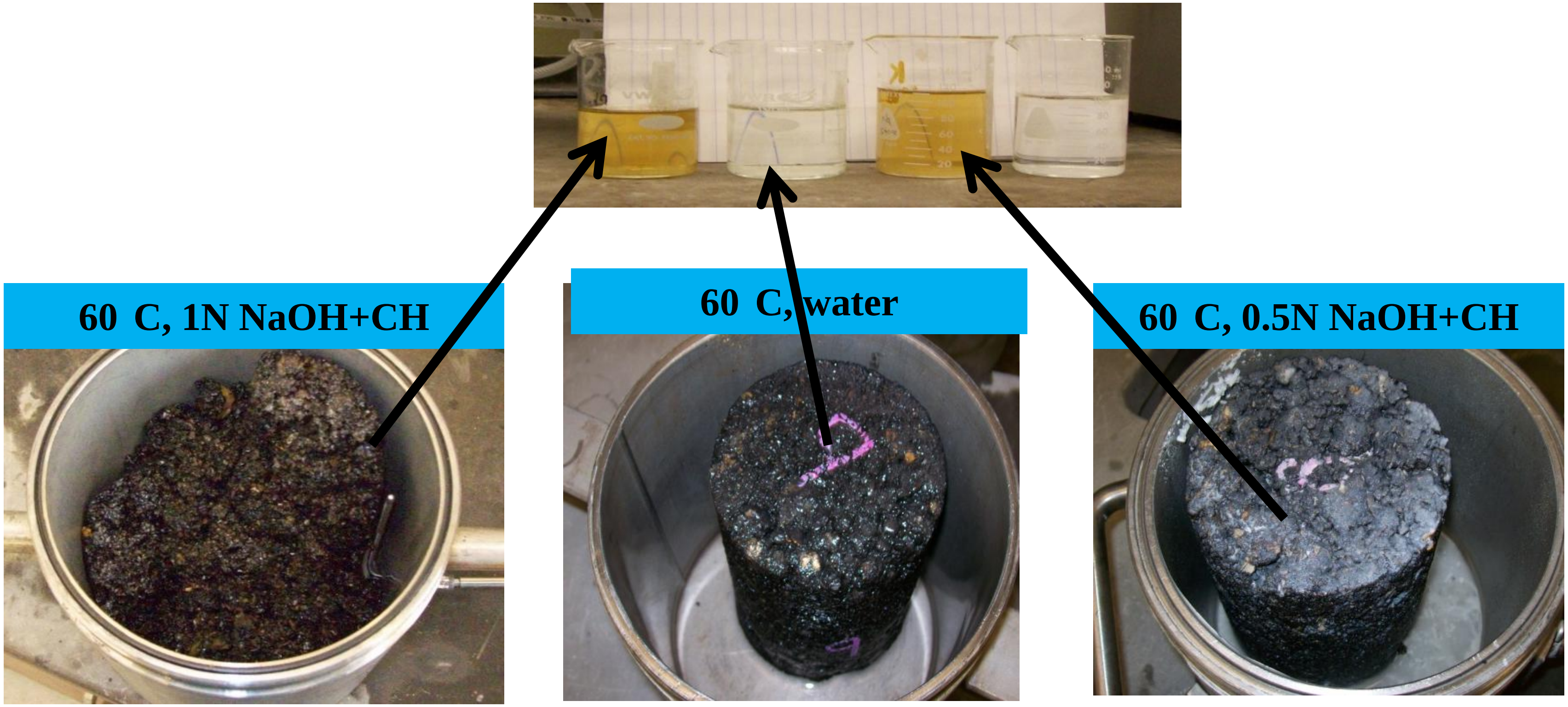


	pH (B)	pH (A)	Na% RDN	OH% RDN
Virgin Chert	14.0	13.1	-41.7	-87.0
4.0% BC	14.0	13.6	-4.4	-61.2
6.5% BC	14.0	13.3	-2.6	-81.6

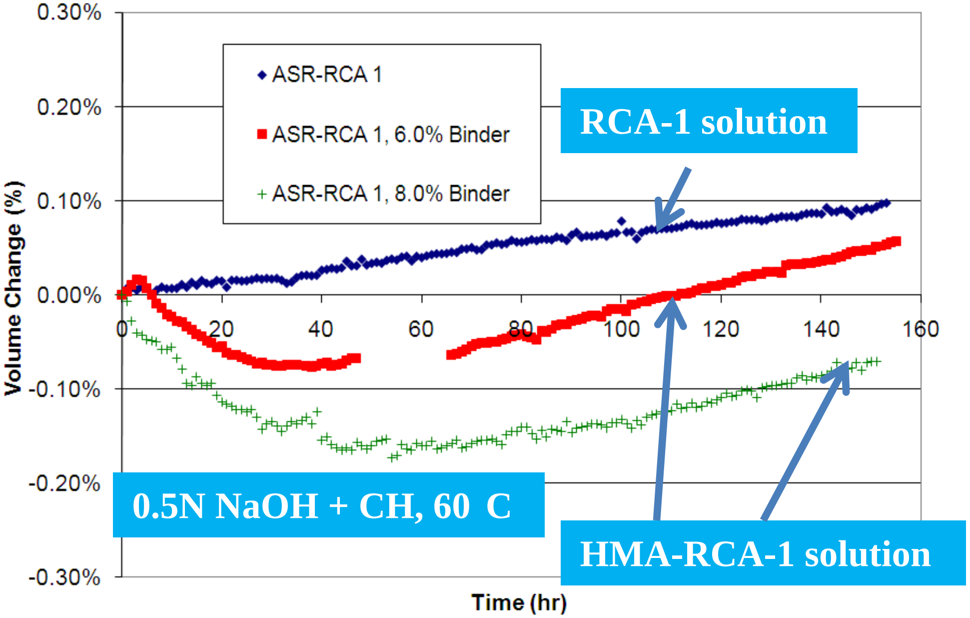
Soak solution chem.

Saponification and Appearance of specimens with Virgin Chert Aggregate

- **The initial swelling is likely due to saponification**
- **Saponification is neutralization of naphthenic acids in the asphalt binder by OH^- ions from NaOH solution, i.e., binder solution interaction**



ASR Testing of ASR-RCAs and HMA with ASR-RCAs

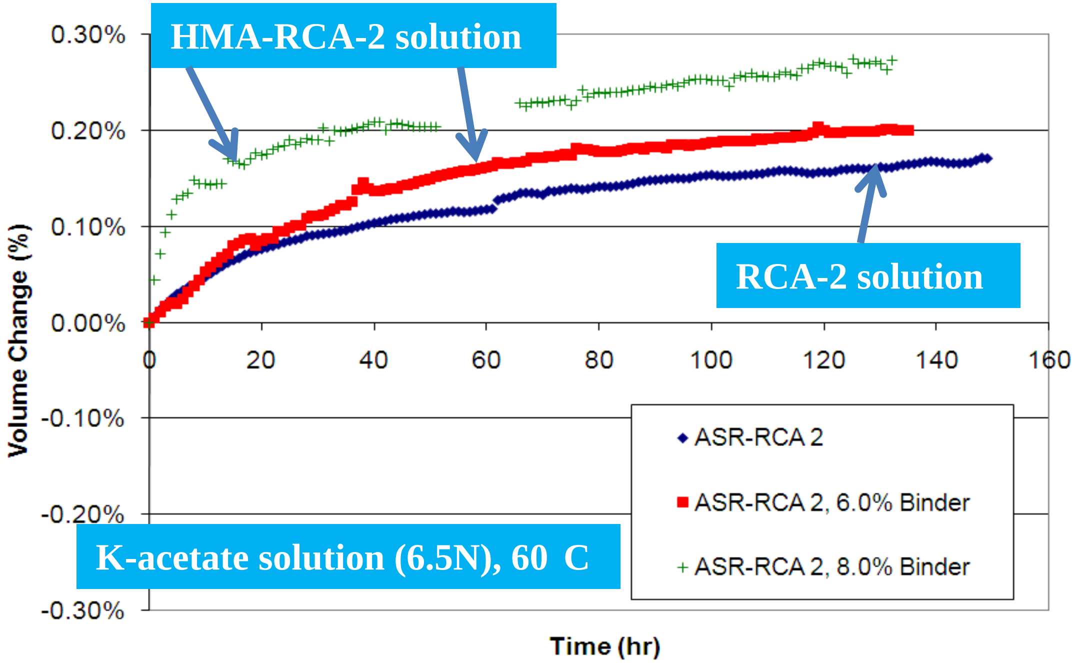


Soak solution chemistry change

	pH (B)	pH (A)	Na% RDN	OH% RDN
RCA-1	13.8	13.3	-69.0	-67.0
RCA-2	13.8	13.7	-27.2	-27.3
RCA-1, 6% BC	13.8	13.2	18.0	-74.0
RCA-1, 8% BC	13.8	13.3	-21.0	-71.0
RCA-2, 6% BC	13.8	13.1	-7.0	-78.0
RCA-2, 8% BC	13.8	13.4	16.0	-62.0

- **Expansion measurement in RCA-1 solution is due to ASR**
  - Reduction of both Na^+ and OH^- in similar magnitude in the soak solution is supporting evidence of ASR
- **Swelling measurement in HMA made using RCA-1 and solution test with both low and high binder contents is mainly due to saponification**
  - Significant reduction of OH^- with negligible reduction of Na^+ in the soak solution is supporting evidence of saponification

ASR Testing with KAC Deicer:
volume and soak-solution chemistry changes

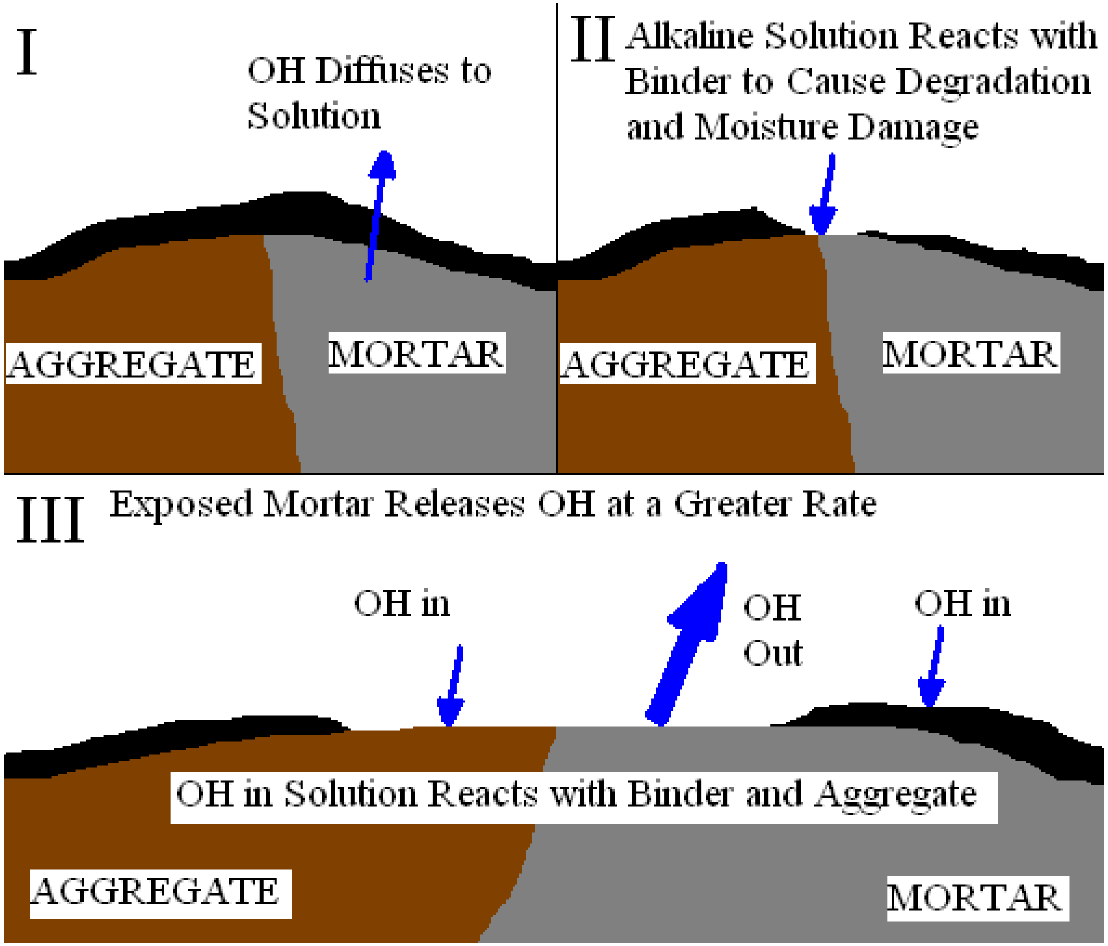


Change of deicer (KAC) soak solution chemistry

	pH (Before)	pH (After)	K% Reduction
RCA-2	10.4	13.7	-41.7
RCA-2, 6.0% BC	10.4	11.8	-26.1
RCA-2, 8.0% BC	10.4	11.2	-20.8

- **Higher pH increase in RCA-solution than in HMA-RCA solution**
- **Expansion measurement in RCA-solution is mainly due to ASR, which is supported by higher reduction of K^+ (~42%) in soak solution**
- **Swelling in HMA-RCA solution is primarily due to saponification during first 30-40 hrs. (greater expansion @ higher rate) followed by little ASR (similar swelling rate for RCA alone and HMA).**
- **Lower reduction of K^+ in HMA-RCA (21-26%) than RCA alone (~42%) indicates less ASR in HMA than RCA alone.**

Possible Reaction Sequences Between ASR-RCA-HMA and Deicer

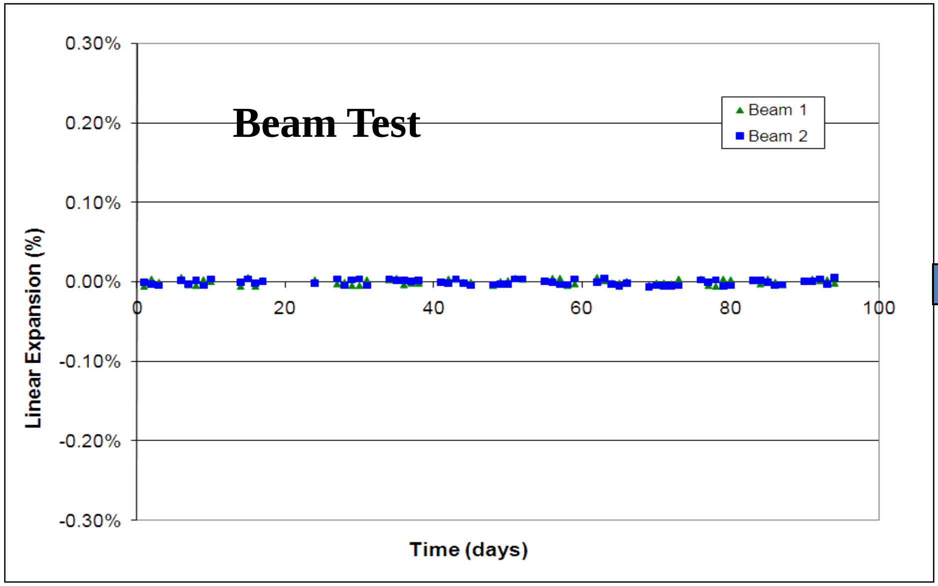


Asphalt film provides some protection

- **Avg. final pH for the high binder specimen is lower than that for low binder specimen** ***- less diffusion and binder-solution interaction in high binder specimens.***
- **Deicer-binder interaction is different and less harmful than (NaOH + CH)–binder interaction**

Beam Test

•3 x 3 x 11.25 inches cut from the original 3 x 6 x 18 inches beam



Any volume change due to binder-solution interaction may not be manifested as any measurable total solid volume change in the field

Moisture Damage (Lottman) Results

	ASR-RCA-1	ASR-RCA-2	Chert
TSR (24 hrs water to dry)	**96%**	**100%**	**80%**
TEA (mJ/g)	**680**	**425**	**295**
	Limestone as CA	**Granite as CA**	**Cryp. silica**

- TSR = tensile strength ratio of specimens conditioned in water specimens left dry at 60 C for 24 hours
- TEA = total energy of adhesion between the aggregate and asphalt binder (**PG 76-22)** as determined by Microcalorimeter

- **No specimen showed a damage index below the 70% TSR limit**
- **ASR-RCA provided more resistance to moisture damage than virgin aggregate**
- **Higher TEA yielded higher TSR – results of micro-calorimeter and Lottman tests are complementary**

Freeze-Thaw and Micro-Deval Results

CA–Coarse Aggregate, FA – Fine Aggregate		Chert (virgin Aggregate)		ASR-RCA-1 (Limestone CA)		ASR-RCA-2 (Granitic CA)	
		CA (12.5 - 4.75 mm)	FA (4.75-0.75 mm)	CA	FA	CA	FA
Micro-Deval	Avg. mass Loss (%)	**5**	**13**	**15**	**13**	**13**	**16**
	COV (%)	**2**	**5.6**	**0.1**	**0.2**	**0.9**	**9.2**
		CA (19.0 - 4.75 mm)	**FA** (4.75-0.30 mm)	**CA**	**FA**	**CA**	**FA**
Freeze-Thaw	Avg. mass loss (%)	**0.7**	**4.5**	**2.8**	**8.0**	**1.1**	**7.0**
	COV (%)	**0.2**	**5.5**	**59.0**	**4.4**	**0.3**	**3.3**

- **F-T test more sensitive than Micro-Deval for detecting the effect of pre-existing micro-cracking due to ASR.**
- **Micro-Deval test of the fine aggregate cannot be considered as a diagnostic tool to select or reject the ASR-RCA fines in HMA.**

Summary

- **ASR-RCA provided good HMA resistance to moisture damage in comparison with virgin aggregate**
- **The primary reaction that occurred in HMA containing ASR-RCA is a saponification reaction**
- **Although some ASR may occur in HMA made with ASR-RCA when exposed to deicer solutions, the distress that it causes should not be significant**
- **The widespread occurrence of any new ASR in HMA made using ASR RCAs is a remote possibility**
- **Field implications and guidelines**

Field Implications

<u>BSI and New ASR</u>

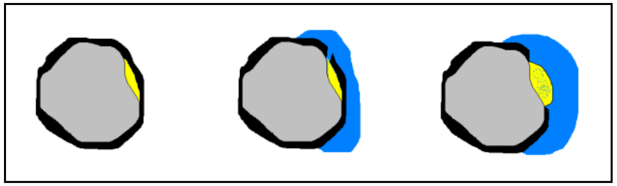
(a) amount of mortar fractions, **(b)** amount of liquid water, **(c)** availability of additional alkalis (e.g., deicers),

Even though alkaline solution formed, the level of alkalinity may be insufficient (pH 11.0-11.5) to cause any measurable new ASR.

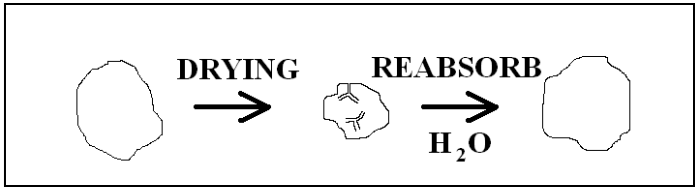
<u>Processing</u> – **(1)** ASR products are likely to concentrate in the finer fractions during crushing and sieving, **(2) gel carbonation** during stockpiling + mixing - carbonated gel will not cause any re-expansion in HMA, **(3) drying process at high temperature** (~ 300 F) in HMA will promote dehydration of gel, which is beneficial to reduce moisture contents in HMA.

<u>Potential Distress Mechanisms</u>

- **Mechanical degradation of the ASR-RCA due to existing ASR micro-cracks**
- **Re-expansion of pre-existing dried unaltered ASR gel**
- **Binder degradation due to binder-solution interaction (BSI) in a wet alkaline solution**
- **New ASR on fresh faces of reactive aggregates**



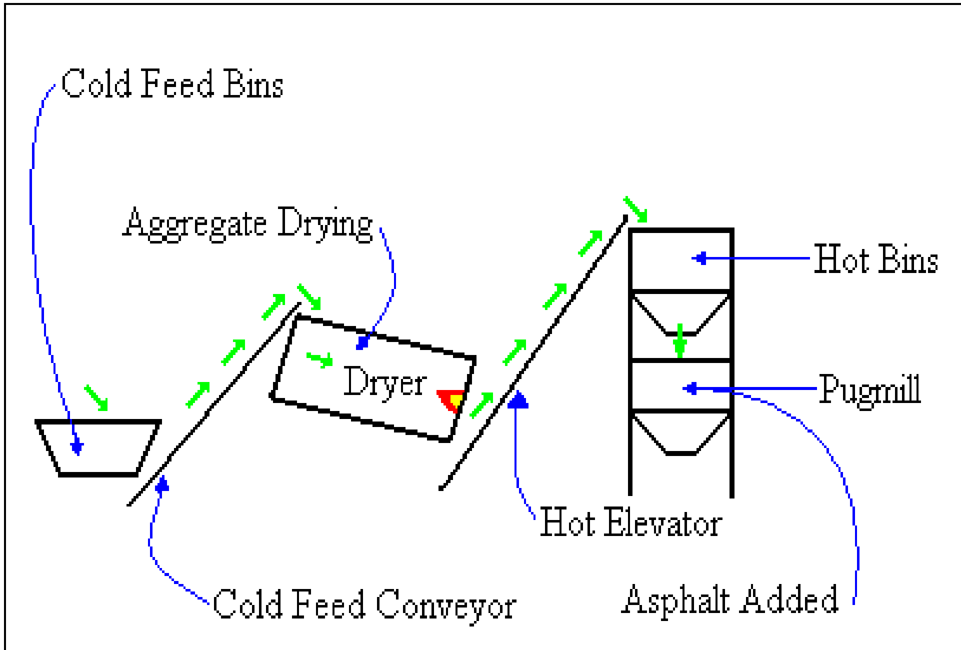
Stripping



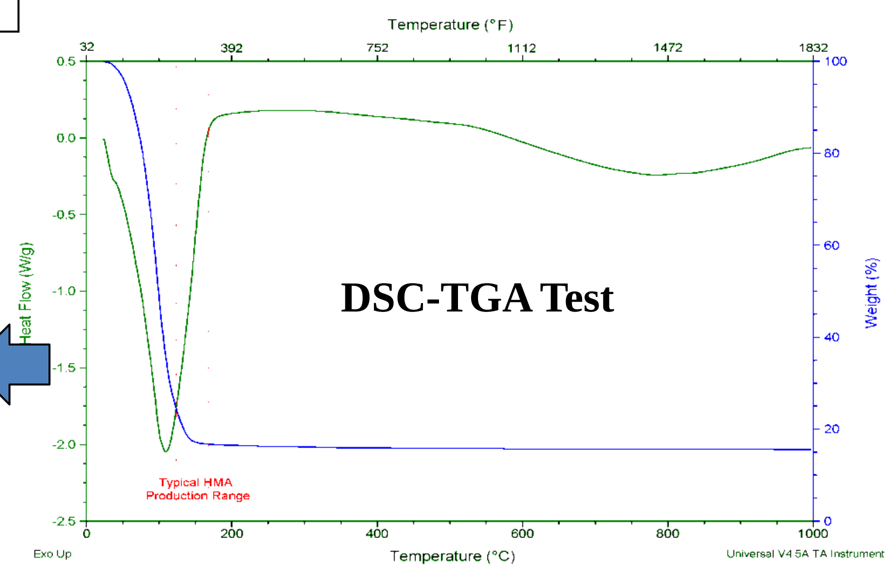
Re-expansion

Microcracks

Effects of Drying and High Temperature During HMA Mixing



Normal drying equipment should be capable of drying the gel. However, extended drying (such as in a batch plant) is preferable to ensure that the gel is dried completely.



Degree of Moisture Damage vs. ASR in the Field

Degree of moisture Damage	Role of ASR
Low	Not enough alkalinity, no BSI / ASR
Medium (i) some loss of adhesive bond and mastics, (ii) strength reduction	BSI / ASR contributes further stripping, which leads to more adhesive failure
High (i) significant loss of mastics and weakening of structure	BSI / ASR has little role for any further damage

Guidelines (Based on Lab. Results and Field Conditions)

PCC Conditions		HMA Conditions			Remediation Measures
Reactivity	Distress	Climate	Traffic	Deicer	
High	High	Severe	High	Yes	(1) harder binder, (2) moisture resistant HMA mix, (3) effective carbonation + extended drying, (4) use of RCA fines and application as a surface course not recommended
High	High	Mild	Low	No	(1) moisture resistant HMA mix, (2) effective carbonation + extended drying, (3) use of RCA fines and as surface course not recommended
Low	Low	Severe	high	Yes	(1) normal drying, (2) may use in surface course with caution, (3) use of RCA fines not recommended
Low	Low	Mild	Low	No	(1) normal drying, (2) may use in surface course with caution, (3) use RCA fines with caution

Use of anti-stripping agent needs to be restricted as anti-stripping agent may provide additional OH^-, which is favorable for ASR. Use of anti-stripping agent may not be needed, as ASR-RCA typically offers better moisture susceptibility.

Future Work

- **Additional research into the impact of ASR-RCA fines on HMA properties is needed**

- **The carbonation rates of ASR-RCA during field storage needs to be measured to provide guidelines for effective storage times**

- **A field study of pavement sections of HMA made using ASR-RCA should be conducted**

Paper Published

1. Mukhopadhyay A.K., Geiger Brian, Button J. (2010), "Use of Alkali-Silica Reaction Affected Recycled Concrete Aggregate in Hot Mix Asphalt, *Journal of Transportation Research Record* (accepted for publication)

2. Mukhopadhyay A.K., Shon Chang-Seon, and Zollinger D.G. (2006) "Activation Energy of Alkali -Silica Reaction and Dilatometer Method", Journal of Transportation Research Board, No. 1979, Concrete Materials

3. Shon Chang-Seon, Mukhopadhyay A.K, Zollinger D.G (2007), "Performance-based approach to evaluate ASR potential of aggregate and concrete using dilatometer method", Journal of Transportation Research Board, No. 2020, Concrete Materials
   - Nominated for practice ready paper award in TRB, D.C., 2007

Thank You

What Question Do You Have?

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